

RELIABILITY ASSESSMENT FOR COTS COMPONENTS IN SPACE FLIGHT APPLICATIONS

G. S. Krishnan
NASA/Goddard Space Flight Center,
Greenbelt, MD 20771 (USA)
Ph: (301) 286 4623 Fax: (301) 286 1743
Email: gskrishn@pop400.gsfc.nasa.gov

Prof. T. A. Mazzuchi (Chair)
SEAS, George Washington University
Washington, D. C. 20052
Ph: (202) 994 7424 Fax: (202) 994 0245
Email: mazzuchi@seas.gwu.edu

ABSTRACT

Systems built for space flight applications usually demand very high degree of performance and a very high level of accuracy. Hence, the design engineers are often prone to selecting state-of-art technologies for inclusion in their system design. The shrinking budgets also necessitate use of COTS components, which are construed as being less expensive. The performance and accuracy requirements for space flight applications are much more stringent than those for the commercial applications. The quantity of systems designed and developed for space applications are much lower in number than those produced for the commercial applications.

With a given set of requirements, are these COTS components reliable? This paper presents a model for assessing the reliability of COTS components in space applications and the associated affect on the system reliability. We illustrate the method with a real application.

INTRODUCTION

The thrust is now on developing systems based on performance and commercial based specifications and standards with concerted efforts to incorporate commercial off-the-shelf (COTS) components [Unkle]. The performance specification states requirements in terms of the required results with criteria for verifying compliance, but without stating the methods for achieving the required results. A performance specification defines the functional requirements for the item, and the application environments. The military standards and specifications are not performance-based specifications. The increased emphasis on use of COTS components stems from a number of reasons. The decrease in military spending

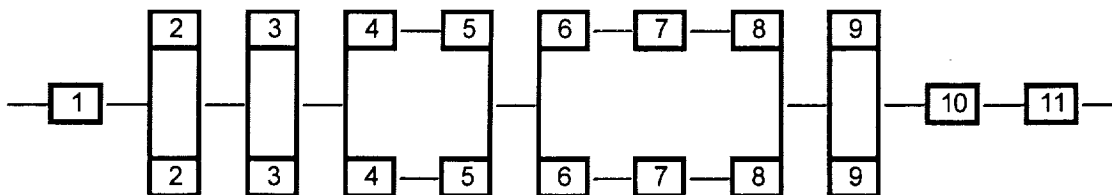
has resulted in the shrinking of the industrial base [Wall]. The technology was driven primarily by department of defense (DoD) in the past, which is no longer the case. The technologies are advancing at such a pace that the government can no longer afford a long acquisition process. Lastly, the vendors are not interested in low volume production to satisfy the needs of the military and space community when their large volume production is consumed in the commercial applications. In recent years, NASA has adopted a faster, better, and cheaper philosophy for space exploration [Chau]. This philosophy mandates space missions to be accomplished with much lower cost, shorter development cycle, and more capabilities than ever. By using COTS in the space flight hardware, it is expected that the development cost as well as the recurring cost of the system can be reduce, thus meeting the goals of the faster, better, cheaper challenges. The use of COTS however poses a big problem when it comes to space applications because of the environmental conditions, the device operating temperature range, the stringent requirements that are imposed on the project, and more importantly the reliability of these COTS under these conditions. The challenges therefore, are how to select, and assess the reliability of these COTS in space applications and their affect on system performance. This paper discusses a model to assess the reliability of COTS and how this model can be practically applied in selecting a component. The paper concludes with recommendations and limitations of this model.

A PROCEDURE FOR HANDLING COMPONENT UNCERTAINTIES IN SYSTEM RELIABILITY ESTIMATION

The problem at hand is the assessment of system reliability given uncertainty about the reliability of one or more of it components. For the purpose of this paper, the following assumptions will be made

Example:

Suppose a mission time reliability for 5 years is desired for the following system of components



Under the assumption of independent components, the system reliability may be expressed as

$$h_s(R) = R_1 [1 - (1 - R_2)^2] [1 - (1 - R_3)^2] [1 - (1 - R_4 R_5)^2] [1 - (1 - R_6 R_7 R_8)^2] [1 - (1 - R_9)^2] R_{10} R_{11}$$

The estimates for the failure rates and subsequent component mission reliability are given in Table 1.

TABLE 1
Available Failure Rate Estimates

Component	Failure Rate (Per Hour) Estimate	5 Year Mission Reliability
1	N/A	0.99000
2	1.825E-06	0.92500
3	Not Available	Not Available
4	3.260E-06	0.87000
5	2.140E-06	0.91263
6	1.122E-06	0.95320
7	1.110E-07	0.99527
8	4.558E-06	0.82307
9	1.253E-06	0.94788
10	3.000E-09	0.99987
11	2.000E-09	0.99991

Note that component 1 experiences no aging effect and that the other components' reliabilities were calculated assuming the exponential failure model. Using the estimates provided in Table 1, the system reliability for a mission time of 5 years can be expressed as

$$h_s(R) = (0.89474)[1 - (1 - R_3)^2]$$

Expert judgment was obtained on component 3. It was determined by comparing similar components that

say $\lambda_L = 2.76E-06$ and $\lambda_U = 2.76E-05$. The results of further elicitation of the expert is given in Table 2. The expert was not able to refine the final interval of $[8.970E-06, 1.158E-05]$ for the failure rate of component 3 and thus the best guess is taken to be the interval midpoint, $1.207E-05$. The length of the interval $[2.76E-06, 2.76E-05]$ is $2.484E-05$ and this value is equated to six standard deviations for the distribution. Given the expert information the following parameters values are obtained.

$$R_L = 0.3076, R_U = 0.8888, \alpha = 0.4980, \beta = 7.999$$

TABLE 2
Determining the Most Likely Interval for λ

Iteration	Lower Interval	Upper Interval
1	[2.760E-06, 1.518E-05]	[1.518E-05, 2.760E-05]
2	[2.760E-06, 8.970E-06]	[8.970E-06, 1.518E-05]
3	STOP	

*bolded interval selected

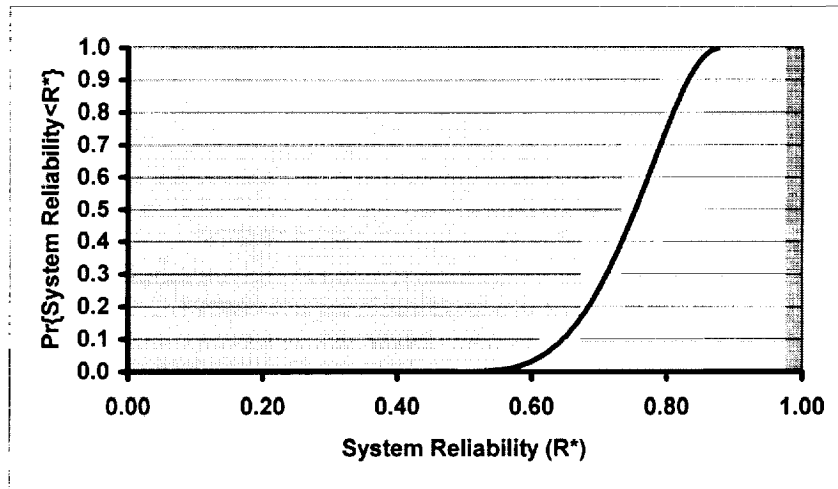
The range for the 5 year mission reliability for component 3 is given as 0.3076 to 0.8888, the expected (and best guess) value is given as 0.4980. The best point estimate of system reliability is given by

$$\begin{aligned}
 E[h_s(\mathbf{R})] &= (0.89474)E([1-(1-R_3)^2]) \\
 &= (0.89474)\{2E[R_3]-(\text{Var}[R_3]+E[R_3]^2)\} \\
 &= 0.7410
 \end{aligned}$$

The above is calculated using the well known identity

$$E[R^2] = \text{Var}\{R\} + E[R]^2$$

Using the distribution for R_3 , probability intervals for system reliability may be determined, for example, see a plot as shown below



$$\Pr\{h_s(\mathbf{R}) < R^*\} = \Pr\{R_3 \leq 1 - [1 - R^*/0.89474]^{1/2}\}.$$

1. The system of components can be expressed as a series-parallel system.
2. The components are independent.
3. Uncertainty exists for only one component, the reliability of the other components are known with certainty.
4. The failure distribution for the component is given by the exponential failure model

$$f(t | \lambda) = \lambda e^{-\lambda t}, \quad \lambda > 0$$
5. Experts may be solicited to provide bounds and a best guess on either the failure or mission reliability.

The assumptions are made in order to make a concise presentation of the procedure, all assumption may be relaxed with increase in theoretical and computational burden.

Given a system of n components, a specific mission time t^* and the known component reliabilities $R_1, \dots, R_{k-1}, R_{k+1}, \dots, R_n$, an expression for system reliability $h_S(\mathbf{R})$ where $\mathbf{R} = (R_1, \dots, R_n)$ can be obtained as a function of the unknown reliability R_k . By expressing uncertainty about R_k through a probability distribution as is common in Bayesian Analysis [c.f. Martz and Waller (1982)], it is possible to obtain both a point estimate of R_k (such as the mean, median, or mode) and thus a point estimate of $h_S(\mathbf{R})$, or probability intervals on R_k and subsequently on $h_S(\mathbf{R})$. For the exponential distribution, component reliability has a

one-to-one relationship with the component failure rate, i.e.

$$R(t | \lambda) = e^{-\lambda t^*}$$

and thus a distribution may be developed for either R or λ depending on expert preference. While engineers are often more comfortable working with failure rates, working with probabilities such as reliability has its advantages in that elicitation procedures may be expressed in terms of potential observed outcomes [c.f. Chaloner and Duncan (1983)]. In the sequel, the engineer's knowledge of the failure rate will be used.

Using an approach similar to that used in PERT analysis [c.f. Hillier and Lieberman (2001)] experts are solicited for the most optimistic and pessimistic values for λ say λ_L and λ_U respectively. Next the expert is asked if it is more likely for the actual value of λ to be in the

interval $\left[\lambda_L, \frac{\lambda_L + \lambda_U}{2} \right]$ or $\left[\frac{\lambda_L + \lambda_U}{2}, \lambda_U \right]$. This

procedure of interval splitting is continued until the expert is not able to continue. The selection of a best guess for λ , λ^* , will be the midpoint of the interval in which the expert stops the splitting procedure.

Given the above, a four-parameter beta distribution can be fit to the component reliability, R , for the specified mission time. The form of the four-parameter beta distribution is given by

$$f(R | R_L, R_U, \alpha, \beta) = \frac{\Gamma(\beta)}{\Gamma(\beta\alpha)\Gamma(\beta(1-\alpha))} \frac{(R - R_L)^{\beta\alpha-1} (R_U - R)^{\beta(1-\alpha)-1}}{(R_U - R_L)^{\beta-1}}, \quad R_L < R < R_U$$

the distribution has mean and variance expressions given as

$$E(R | R_L, R_U, \alpha, \beta) = \alpha(R_U - R_L) + R_L$$

$$Var(R | R_L, R_U, \alpha, \beta) = \frac{\alpha(1-\alpha)}{(\beta+1)} (R_U - R_L)^2$$

The fit is facilitated by setting the pessimistic (optimistic) value for R to R_L (R_U), the best guess for R to the expected value and six times the standard deviation of R to the distance $R_U - R_L$. This results in a specification of the four parameters as

$$R_L = e^{-\lambda_U t^*}, R_U = e^{-\lambda_L t^*}, \alpha = \frac{e^{-\lambda^* t^*} - R_L}{(R_U - R_L)}, \beta = 36\alpha(1-\alpha) - 1$$

CONCLUSION

A procedure has been illustrated for capturing the uncertainty for a component reliability and using this uncertainty to model the corresponding uncertainty in system reliability. This procedure may be used for system reliability assessment and the assessment of mission risk. The model is based on many assumptions, most of which may be relaxed with only computational burden. Three assumptions however, are critical and need to be explored before employing these results. First, the assumption of independence is quite common but often suspect. The second critical assumption is that the other component reliabilities are known with certainty. As this is usually not the case, uncertainty with respect to all components should be considered. Thirdly, the reliability numbers are based on the elicitation from an expert. This however could vary from one expert to another. The best results could be obtained if the elicitation process is done over a pool of experts rather than a single expert.

REFERENCES

- Chaloner, K. M., Duncan, G.T., "Assessment of a Beta Prior Distribution: PM Elicitation". *The Statistician*, pp. 174-18, 1983.
- Hillier, F. S., Lieberman, G. J. *Introduction to Operations Research*, 7th Edition, McGraw-Hill, 2001.
- Martz, H. F., Waller, R. A. *Bayesian Reliability Analysis*, New York: Wiley, 1982.
- Unkle, C. R, *Impacts on Reliability of Recent Changes in DoD Acquisition Reform Policies*, RAC START Volume 3, Number2.
- Wall, J, *COTS-EEE components and plastic encapsulated semiconductors for space application*, Defence Evaluation and Research Agency, UK.
- Chau, Savio, *Experience of Using COTS Components for Deep Space Missions*, Proc. of the 4th IEEE International Symposium on High Assurance Systems Engineering, 1998.